An Empirical Assessment of Pavement Roughness in the US

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January 10, 2009

Presented at the 88th Annual Meeting of the Transportation Research Board.
Washington DC, January 11-15, 2009.

ABSTRACT

This study uses aggregate state-level data spanning 1999-2006 to examine the relationships between pavement performance, and preservation expenditure, dominant surface geology, and climate. To account for possible random variations in parameters across geographic locations and time periods, a random parameters logit (mixed logit) model was used. The analysis, carried out separately for roads in different functional classes, expresses performance as the relative proportions of pavements in the Federal Highway Administration's (FHWA)-defined performance categories. The results of the analyses showed the extent to which increased preservation spending yields increased pavement performance and the nature of this relationship for the different regions of climate and surface geology. Also, using pseudo-elasticity analysis, the paper shows the nature of the expected shifts across the performance categories in response to changing levels of preservation expenditure or to different levels of the other explanatory factors. The models can be used by federal level oversight personnel to assess the impact of increasing or decreasing preservation funding on the pavement performance either for the entire national network or for selected states or regions with known climatic condition and dominant surface geology.

INTRODUCTION

Highway agencies spend billions of dollars annually on preserving their pavements and they continually seek to enhance oversight mechanisms not only to ensure that these investments are yielding their worth but also to ascertain the impact of changing funding levels on pavement performance. Agencies also seek to investigate these relationships from the perspective of the different climatic conditions (such as freeze and precipitation) and different conditions of surface geology (which ultimately translates into geotechnical integrity of the subgrade or of the material underlying the subgrade in the case of fill sections).

The influence of surface geology and climate on pavement performance has been long recognized in pavement engineering and management. There has been a great deal of research that has established mechanistic and empirical relationships between performance and other factors such as subgrade strength (which often is a reflection of surface geology) and freeze conditions, precipitation, and freeze-thaw transitions (*1-3*). Most of these studies have been at a disaggregate level that utilized information on truck loading and other project-specific data (*4*). Relatively few studies have examined the relationships from an aggregate level using statewide data.

Using random parameters logit (mixed logit) models to account for possible random variations in parameters across the 51 States of the United States and an 8-year data period (1999-2006), this paper investigates, for the national road system, the relationship between the performance of the pavement network and the level of pavement preservation spending in the previous year, the nature of surface geology, and the climatic conditions. Depending on values of average roughness, pavements in each state and functional class were placed in performance categories. These categories were established by the Federal Highway Administration (FHWA) of the US Department of Transportation (DOT) and are used as a basis for reporting and monitoring national network pavement condition. The performance categories are based on the International Roughness Index (IRI) as follows: Excellent – IRI < 60 in/mi; Good – IRI is 60-94 in/mi; Fair – IRI is 95-170 in/mi; and Poor – IRI exceeds 170 in/mi.

The analysis was carried out separately for each category and also for each area class (urban and rural) and functional class (interstates, other freeways and expressways, principal and minor arterials, and collectors). Unlike the more traditional pavement performance analyses that utilize detailed, project level data (such as traffic loading, precipitation, freeze index, preservation history, and pavement age) an aggregate analysis is used herein. Although aggregation often introduces additional heterogeneity across observations, the aggregate approach can potentially mitigate interactions and biases that are inherent with such project-level disaggregate analysis and allow for a more general investigation of spatial variables.

METHODOLOGY

To account for unobserved heterogeneity arising from the exclusion of project-specific variables, the paper utilizes an approach that allows for the possible variation of influential variables across the States. This is important because, due to variations in road sections for example, it cannot be assumed that effects of the excluded variables on pavement performance are the same for all States. To address such unobserved heterogeneity, relatively recent research (*5-7*) has demonstrated the effectiveness of the mixed or random parameters logit model, a methodological approach that can be used to explicitly account for the variations (across States) of the effects that the excluded variables could have on the response variable.

For each state, the mileage proportions of pavements in each performance category (the proportions of the number of miles for excellent, good, fair and poor IRI), are determined. Consistent with model forms in past similar research (*8, 9*), the inventory fraction is modeled as:

$$T_{in} = \beta_i \times X_{in} + \varepsilon_{in} \tag{1}$$

where T_{in} is the inventory fraction in performance category i in State n; X_{in} is a vector of exploratory variables (past inventory of performance category i, preservation expenditure, and climate and surface geology); β_i is a vector of estimable parameters for outcome i which may vary across observations, and ε_{in} the error term which is assumed to be independently and identically, extreme value Type I distributed.

The variation of β_i is with density $q(\beta_i \mid \phi)$, where ϕ is a vector of parameters of the density distribution, also referred to as mixing distribution. The outcome probabilities (mileage proportions in the four performance categories) in the mixed logit model are as follows (*8*):

$$P_n(i \mid \phi) = \int \frac{e^{\beta_i X_{in}}}{\sum_{\forall I} e^{e^{\beta_I X_{In}}}} q(\beta_i \mid \phi) d\beta_i \tag{2}$$

where, $P_n(i \mid \phi)$ is the outcome probability conditional on $q(\beta_i \mid \phi)$; all other terms are as previously defined.

For model estimation, β_i can now account for performance-specific variations of the effect of X on the inventory fractions (or probabilities) of each performance category, with the density function $q(\beta_i \mid \phi)$ used to determine β_i. Mixed logit probabilities are then a weighted average for different values of β_i across States where some elements of the vector β_i may be fixed and some may be randomly distributed. If the parameters are random, the mixed logit weights are determined by the density function $q(\beta_i \mid \phi)$. The mixed logit model is an adaptable modeling approach that overcomes the Independence of Irrelevant Alternatives property of the standard multinomial logit model and allows β_i to vary across observations (*9, 10*).

The required numerical integration of the logit function over the distribution of the random parameters renders the maximum likelihood estimation of the mixed logit model rather computationally cumbersome. As such, a simulation-based maximum likelihood method is used. A popular simulation approach using Halton draws has been shown to provide a distribution of draws for numerical integration that is more efficient than purely random draws (*11-13*). The evolution of simulation-based maximum likelihood methods for estimating mixed logit models are provided in the literature (*7, 14-17*).

The distinction between the multinomial and mixed logit model is found on the error term ε_{in}. In the traditional multinomial logit context (*18*), the ε_{in} (unobserved effect) is assumed to be extreme-value independent and identically distributed. The mixed logit relaxes this assumption by accounting for correlation across and within possible outcomes. In functions that determine the inventory fraction of each performance category in individual States, it is important to accommodate the possibility of shared unobserved effects among the outcomes. Traditional multinomial logit models assume that the alternate outcomes are independent – if not, an error arises in the model estimation. It is expected that different outcomes (different performance categories) may share unobserved effects that would result in error term correlation. Such a problem could be resolved by using a nested logit formulation (*19*), however the mixed logit used in this paper addresses this problem by incorporating a more general error correlation structure.

Finally, to assess the individual parameter estimates of the mixed logit model elasticities are computed. Elasticities give the relationship of an independent variable on the outcome proportions, and are expressed as the percent effect a 1% change in the independent variable has on the outcome proportion probabilities. Elasticities are considered to be the correct way of expressing the impact of each variable in the model, and are defined as (*9*):

$$E_{x_{in}}^{k_i} = \frac{\partial k_i}{k_i} \times \frac{x_{in}}{\partial x_{in}} , \tag{4}$$

where E the elasticity, x_{in} the value of the n^{th} independent variable for observation i, and k_i the expected frequency. Although elasticities are computed for all observations separately, to have a single elasticity estimate for an independent variable over each one of the IRI-category levels, the average elasticity over all observations is computed. The elasticity in Equation 4 is appropriate only for continuous variables; for categorical variables the pseudo-elasticity can be computed (*9*):

$$E_{x_{in}}^{k_i} = \frac{e^{\beta_n} - 1}{e^{\beta_n}} , \tag{5}$$

where β_n is the estimated parameter for the n^{th} independent variable. The pseudo-elasticities give the % change in outcome proportions caused by changes in the categorical variable.

Data and Empirical Setting

Data were obtained from the Highway Statistics annual and summary reports prepared by the Office of Highway Policy Information of the FHWA (*20*). The data include the number of miles by performance categories and preservation expenditure for each of the 51 States by road functional class for an 8 year period (1999-2006). The road functional classes are: rural interstates, rural principal arterials, rural minor arterials, rural collectors, urban interstates, urban other freeways and expressways, urban principal arterials, urban minor arterials, and urban collectors. Data on climate and surficial geology (Figures 1 and 2) were obtained from available literature (*21, 22*).

Pavement performance, typically, is a function of factors such as loading, climate, pavement type and thickness, and underlying subgrade quality. With regard to climate, the study utilizes the four LTPP climatic zones: wet–freeze, wet–non-freeze, dry–freeze, and dry–non-freeze (Figure 1(a)). Details on the difference between these climatic zones have been well explained in the literature (*23*).

With regard to subgrade, the quality of the natural surficial soil can be a critical determinant of pavement performance, particularly for pavements that were founded directly on existing ground, often, cut or level sections. On the basis of soil particle size, the four major classifications of soil are clay, silt, sand, and gravel. From clay to gravel, there is increasing granularity, decreasing plasticity, and generally, increasing competence as a subgrade material particularly under wet conditions. On the basis of the nature of soil formation, pedologists have mapped out the United States into eight surficial geological zones: glacial soils, residual soils, filled valleys and outwash, coastal plain soils, alluvium, lacustrine soils, loess, and clay/organic soils (Figure 1(b)) – these largely dictate the type and quality of pavement subgrade soils found in those areas.

Glacial and Outwash soils include those of the young Wisconsin Drift and older drifts (Kansan, Nebraskan, and Illinoian drifts). As these ice sheets drifted across the continental land mass and melted, they deposited accompanying debris and soil in areas known as outwash. In the New England states, the drift is generally shallow and is granular to semigranular in nature. The principal soil engineering problem in this region is that of frost action (see LTPP climate map in Figure 1(a)) (*21*). The general shallowness of the drift results in problems of drainage, which compromises soil strength particularly when the deposited material contains interbedded silts and clays. Moving westward to the central portion of the United States, the engineering integrity of the glacial surficial soils is reduced not only by frost action but more by the cyclical freeze-thaw transitions that foster spring-time breakup of pavements. In this region, the underlying pavement subgrade is primarily the material deposited by the drift which is largely silty to silty clay. However, sandy material can be found in terraces, kames, eskers, and outwashes. Specifically, in the Great Lakes region of the upper Midwest, there are postglacial landforms that include a multiplicity of lakes, and the frequent pockets of muck and peat bogs that arise from the damming of drainage areas. In some of these areas, the surface geology consists of a diverse mix of sediments with highly variable hydrogeologic properties and lithographic discontinuities (*23*) and in some of these areas, typical pavement problems include poor subgrade support (*25*). Other areas are dominated by a layer of unconsolidated drift soils that was deposited during the advances and retreats of the Wisconsinian and older glaciations. Areas with unconsolidated glacial deposits have clay-rich loamy tills interbedded with stratified sands and gravels. Thus, the character of glacial deposits varies across the locations and depends on the conditions at the time of glacial meting and subsequent deposition of the soil. Outwash regions are dominated by granular material (which serve as good subgrades) but in certain dammed-up drainage locations may contain muck and peat deposits that are poor subgrade material.

Residuals soils are those that are derived from parent material. The areas of the country dominated by residual soils include the Piedmont, Valley and Ridge Province, and Bluegrass regions. In the Piedmont region (which extends from Georgia up through the Carolinas into Pennsylvania), the subgrades are borne of material that are derived from parent bedrocks of granites, schists and gneisses. These soils tend to be highly micaceous and generally have a sandy texture, with relatively deep soil mantle on top of the parent rock (*22*). Due to the micaceous nature of the surficial soils in this region, the pavement related problems in this area include difficulty of compaction and poor subgrade support. In the Valley and Ridge Province where the bedrock consists of limestone, sandstone, and shales, the soils are generally plastic, and this leads to serious subgrade problems, particularly in areas where poor drainage contributes to a drastic reduction in the bearing strength of such soils. In the bluegrass region of Kentucky and the Great Valley (extending from Pennsylvania through Virginia and the Carolinas), limestone bedrock yields extremely plastic soils that serve as poor subgrades.

Lacustrine (lake-laid) soils are found in relatively small areas around glacial areas. These include some areas of the great Lakes (south of Lakes Erie, Huron, and Michigan) and parts of Minnesota and North Dakota. These soils are generally plastic and have high water tables. Thus they generally perform poorly as subgrades. To avoid problems with subgrade at such areas, some highways have been located along granular beach deposits (*23*). For highways in other areas of this soil region, particularly the lake-bed areas of northern Michigan, Minnesota, and North Dakota where silty surficial soils are encountered, frost action may lead to poor pavement performance.

Alluvial soils, which include areas adjacent to the Mississippi River, are clayey and thus exhibit high plasticity. Combined with high groundwater table, this characteristic constitutes a particularly unfavorable subgrade environment for highway pavements in the region.

Loess is a porous, friable, fine-grained, windblown sediment. The loessial soils include areas of Mississippi Tennessee, Illinois, parts of Wisconsin, parts of Iowa, and parts of Nebraska and Kansas. In the undisturbed state, this material is very stable but if disturbed becomes difficult to compact as a subgrade or fill material. Also, wind-deposited material of a sandy nature that are found in Colorado, Nebraska, south of Lake Michigan, can serve be competent if they are used in-situ as subgrades.

The Coastal Plain soils are found in the narrow band adjacent to the Atlantic Ocean on the East Coast and extend along the Gulf of Mexico. With regard to their quality as subgrades, the soils in this area vary considerably, from highly plastic clays (in Texas, Louisiana, Alabama, and Mississippi) to granular material. In such areas, therefore, the performance of pavements depends on the amount or precipitation.

Notwithstanding these generalizations, there is marked local variability in surficial soils, and pavement subgrades in the country often can vary considerably over relatively short distances.

A total of 408 observations (51 States by 8 years) were defined. For each observation, the data were sorted by road functional class, and individual performance (IRI) category data reports on the States were aggregated. For each state and year, the inventory fraction of each performance category was determined. Table 1 provides summary statistics on key variables.

MODEL ESTIMATION RESULTS

Equation (2) is estimated by specifying a functional form of the parameter density function ($q(\beta_i \mid \phi)$) and using simulation-based maximum likelihood with 200 Halton draws (this number of draws has been shown empirically to produce reliable parameter estimates (*8, 11*)). For the functional form of the parameter density functions, the normal, lognormal (which restricts the impact of the estimated parameter to be strictly positive or negative), triangular and uniform distributions, were considered. With the functional forms of the parameter density functions specified, values of β_i are drawn from $q(\beta_i \mid \phi)$, logit probabilities are computed, and the likelihood function is maximized. Tables 2 and 3 present the model's estimation results for rural and urban road functional classes, respectively; Table 4 presents the goodness-of-fit of the estimated models. Table 5 illustrates the estimated average elasticities and pseudo-elasticities over all observations, and Table 6 summarizes the major findings.

In Tables 2 and 3 it is observed that all variables incorporated are significant and the signs are plausible. Table 4 shows that all models have a good overall fit (R^2 within 0.54 to 0.71). A random parameter is determined as significant when the standard deviation of the parameter density is statistically significant. If its estimated standard deviation is not statistically different from zero, the parameter is fixed to be constant across the population. For all the random parameters, the normal distribution was found to provide the best fit.

As seen in Tables 2 and 3, for the Excellent performance category, the constant term for rural interstates (2.32) and collectors (-1.05) is fixed, but is random for rural principal and minor arterials. The constants for rural principal and minor arterials result in random parameters, with means 1.48 and 0.77, and standard deviations 1.03 and 0.93, respectively. Both the mean and standard deviation are statistically significant indicating that the parameter effect varies over the sample. Given these distributional parameters 92.4 and 79.5 percent of the distribution is less than zero and 7.6 and 20.5 percent is greater than zero for the rural principal and minor arterials, respectively.

For the Good performance category, the constant term is random for rural interstates but is fixed for principal arterials (2.6), minor arterials (1.55), and collectors (0.43). The constant for rural interstates results in a random parameter, with mean 3.27, and standard deviation 2.02. Both the mean and standard deviation are statistically significant indicating that the parameter effect varies over the observations. Given these distributional parameters 94.7 percent of the distribution is greater than zero and 5.3 percent is less.

For the Fair performance category, we also find the constant term to be random for rural interstates and collectors but fixed for rural principal arterials (2.21) and minor arterials (1.48). Again, the constants for rural interstates and collectors result in random parameters, with means 2.29 and 1.09, and standard deviations 1.03 and 1.01, respectively. Both the mean and standard deviation are statistically significant indicating that the parameter effect varies over the sample. Given these distributional parameters 98.7 and 85.9 percent of the distribution is less than zero and 1.3 and 14.1 percent is greater than zero for the rural interstates and collectors, respectively.

These results imply that only for a small proportion of States do we see a decrease in the proportion of: Excellent performance category for rural principal arterials and minor arterials; Good performance category for rural interstates; and fair performance category for collectors. Thus, for most states, we see an increase in these aforementioned proportions. This finding has important implications in that it suggests that (all else being equal) it is generally more likely for the majority of the States to have a greater proportion of good performance pavements and less likely for them to have a larger proportion of poor performance pavements. However, due to the random parameters, this may be different for some individual states.

For the urban road models, the results for the constant terms show some consistency with the rural road models. We find the constant term in the Excellent category is fixed for interstates, other freeways/expressways, and collectors, but random for urban principal arterials (with 12 percent of the distribution being greater than zero, and 88 percent being below) and minor arterials (with 6.9 percent of the distribution being greater than zero, and 93.1 percent being below). For the Good performance category, the constant term is found to be random for urban interstates (with 95.8 percent of the distribution being greater than zero, and 4.2 percent being below) and collectors (with 7.5 percent of the distribution being greater than zero, and 92.5 percent being below), but is fixed for urban principal and minor arterials, and other freeways/expressways. Finally, for the Fair performance category, the constant terms are all found to be fixed. These findings have important implications in that they suggest that for urban interstates and other freeways/expressways, it is more likely (all else being equal) for a State to have a higher proportion of Good performance pavements and less likely for it to have Poor performance pavements. Furthermore, for urban principal and minor arterials it is more likely (all else being equal) for a State to have a higher proportion of Fair performance pavements and less likely for it to have a higher proportion of Excellent performance pavements. For urban collectors, it is more likely (all else being equal) for a state to have a higher proportion of Poor pavements and less likely for it to have a higher proportion of Excellent pavements. However, as reflected in the value of the random parameters, it is worthy to note that this finding may be different for certain states. Hence, on the basis of the constant terms, the proportion of pavements in each performance category, for both rural and urban roads, cannot be assumed to be uniform across geographic locations (States) and time periods (years within the data period).

With regard to the variable representing the number of miles (in hundreds) with IRI value corresponding to each performance category in period *t*-1 (given that the response variable is in period *t*), we find it to be significant in all performance category functions and all rural and urban road functional classes (except for the urban interstates model). Table 2 shows that for all the rural road functional classes and pavement performance categories, there is a positive relationship between the proportion of miles in that category in a given year and that in the previous year. However, the variables' effect is not the same across observations. In the rural minor arterial model, for Excellent pavements category, the variable yields a random parameter (87.6 percent of the distribution being greater than zero, and 12.4 percent below). In the rural collector model, for the Good pavements category the variable results in a random parameter (93 percent of the distribution being greater than zero, and 7 percent below). In the rural interstate, principal and minor arterial models, for the Fair pavements category the variable also yields random parameters (5.5, 3.8, and 6.9 percent of the distribution being greater than zero, and 94.5, 96.2, and 93.1 being below, respectively).

Table 3 shows that for all urban road functional classes and performance categories (the only exception is the urban interstates' Poor performance category) there is a positive relationship between the number of miles in each performance category at any year and that in the preceding year. However, the variables' effect is not the same across observations. In the urban collector model, for Excellent performance category the variable results in a random parameter (78.1 percent of the distribution being greater than zero, and 21.9 percent below). In the urban principal and minor arterial models, the variable also results in random parameters for the Good performance category (76.6 and 87.5 percent of the distribution being greater than zero, and 23.4 and 12.5 percent below, respectively), and in the urban principal and minor arterial models for the Poor performance pavements (89.4 and 85.8 percent of the distribution being greater than zero, and 10.6 and 14.2 being below, respectively).

The variable representing the preservation expenditure (in million US dollars) in a preceding year was found to be significant in all models. In the rural interstate and collector and urban principal and minor arterial models, the variable was found to be positively related with the response variable for the Excellent performance category, indicating that the more money is spent for preservation, the higher the proportion of number of miles with excellent pavements. In the rural principal arterial and urban collector models, the preservation expenditure was found to be positively related with the response variable for the Good performance category. For Fair pavement on the rural principal and minor arterial and collector, and in the urban interstate and minor arterials, the preservation expenditure was found to have a negative sign, indicating that the higher the preservation expenditure, the lower the proportion of Fair performance pavements. This is intuitive. Also, in the rural interstate, minor arterial and collector, and in the urban other freeways/expressways models, the preservation expenditure was found to be negatively related with the response variable, indicating that the higher the preservation expenditure in the Poor performance category, the lower the proportion of pavements, subsequently, for that category.

Moving to the topology variables, we find a number of climate and surface geology characteristics play an influential role in determining network level pavement performance, specifically, the mileage proportions in the different performance categories. For most functional classes, the results suggest that compared to States in other regions, location in 'freeze' or 'wet' zones (Figure 2a), are negatively related to the mileage proportion for the excellent and fair performance categories but positively related to the mileage proportion for the fair and poor performance categories. That is, compared to states in other locations, State located in a 'freeze' or 'wet' zone are more likely to have lower proportions of pavements in the excellent and good performance categories and higher proportions in the fair and poor performance categories. On the other hand, compared with states in other regions, States located in 'non-freeze' and 'non-wet' zones are more likely to have higher proportions of pavements in the excellent and good performance categories and lower proportions of fair and poor performance pavements. However, for some road functional classes, these results are not uniform across observations. The 'wet' zone indicator variable in the rural collector model is found to be a random parameter for both the Good and Fair performance categories (5.5 and 92.8 percent of the distribution exceed zero, and 94.5 and 7.2 below, respectively). The same variable also results in a random parameter in the urban principal arterial model for the excellent IRI category (8.7 percent of the distribution exceeds zero, and 91.3 is below zero). The "freeze zone" indicator variable in the rural and urban minor arterial models, are also found to be random parameters for the fair and poor IRI categories, respectively (with 89.7 and 91.8 percent of the distribution being above zero, and 10.3 and 8.2 below, respectively).

Tables 2 and 3 show that the surface geology variables have widely varying impacts. The findings suggest that climate and surface geology clearly influences the relative proportions (by mileage) of pavements in the different performance categories but the effect of these parameters is not uniform across locations and time periods.

SUMMARY AND CONCLUSIONS

This study investigates the pavement condition at a nationwide level, using roughness and expenditure data aggregated by State. The entire United States is divided into zones with different climate (precipitation and freeze conditions) and the predominant surface geology. A demonstration of random parameters logit (mixed logit) model is provided as a methodological approach to gain new insights into the factors that significantly influence pavement performance proportions by mileage. From an econometric point of view, the mixed logit model allows for possible random variations in parameters across geographic locations (States) and time periods (years) and the flexibility to possibly capture any heterogeneity in pavement performance arising from project-specific data such as road geometrics, traffic use, pavement design, and so on. Another appealing aspect of the mixed logit model is the flexibility provided in capturing correlation across pavement performance categories.

Using 1999-2006 data from FHWA's Highway Statistics annual and summary reports prepared by the Office of Highway Policy Information, this paper discusses models developed separately for rural and urban interstates, principal and minor arterials, and collectors, and urban other freeways and expressways. The results provide some interesting findings. For example, a variety of factors were found to significantly influence pavement performance proportions including the preceding year's pavement performance, preservation expenditure, climate conditions, and surface geology.

Over 51 random parameters were determined to be significant in all the developed models (including the constants, the preceding year pavement performance and preservation expenditure, climate conditions, and surface geology types), and for all of these, the normal distribution was found to provide the best fit.

While this study is exploratory in nature, it does suggest the considerable potential that mixed logit model has in analyzing pavement performance proportions. The ability to directly relate pavement, expenditure and physical factors to pavement performance proportions (by mileage) furthers the understanding of the interaction of the variables that determine pavement performance and the efficiency of perseveration funding on a system-wide level.

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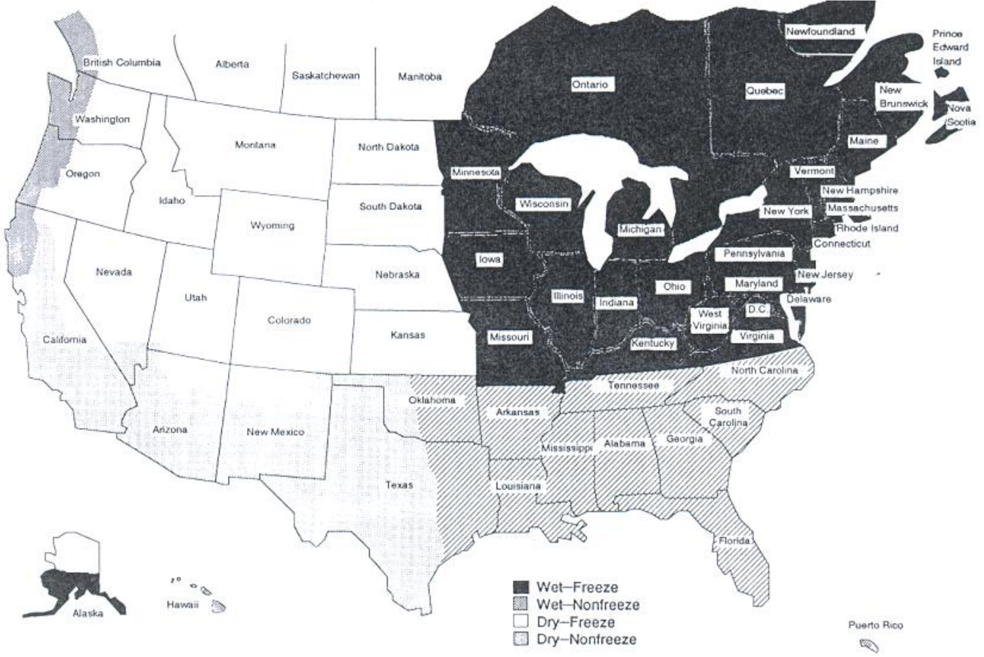
(a) SHRP Climate Zones



(b) Surface Geology

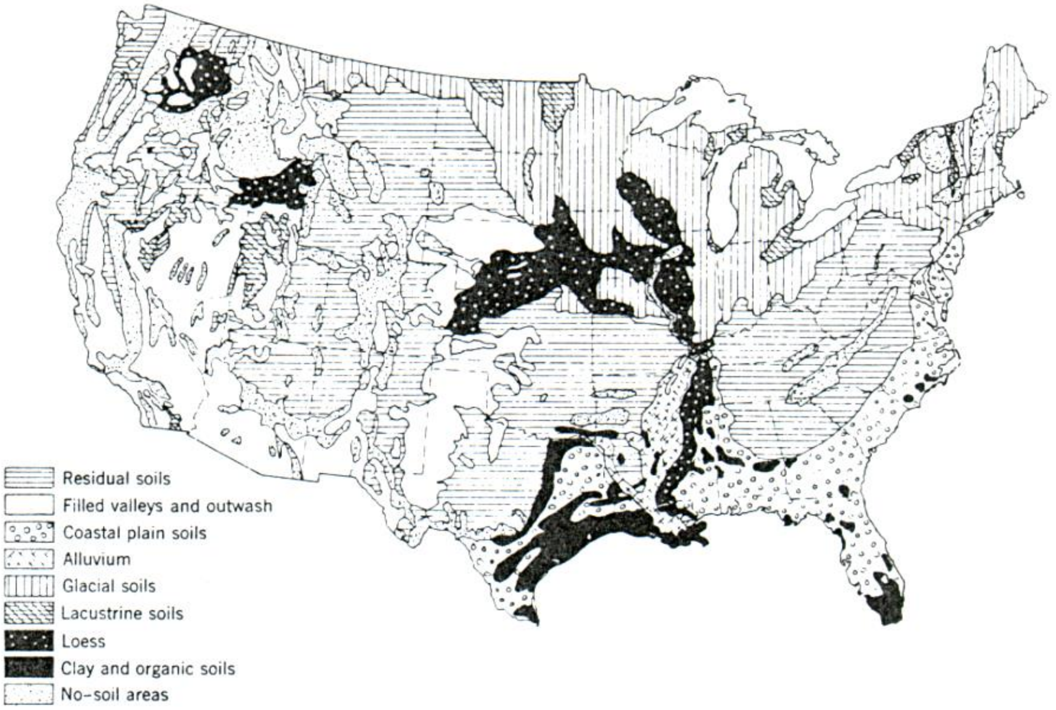


FIGURE 1 State-level Distribution of Surface Geology and Climate (Source, ***20*****,** ***21*****)**

TABLE 1 Descriptive Statistics of the Average Number of Miles per State per Year for the IRI Categories and of the Average Preservation Expenditure per State per Year

		Mean	Std.Dev.	Min	Max
RI	Avg. No. of miles per State per year with IRI less than 60in/mi	169.04	187.74	0	882
	Avg. No. of miles per State per year with IRI between 60-94in/mi	282.53	228.65	0	1,401
	Avg. No. of miles per State per year with IRI between 95-170in/mi	163.79	168.52	0	911
	Avg. No. of miles per State per year with IRI greater than 170in/mi	12.53	23.96	0	136
	Avg. Preservation expenditure per State per year (in million US dollars)	63.81	66.49	0	430.33
RPA	Avg. No. of miles per State per year with IRI less than 60in/mi	302.90	377.33	0	2,123
	Avg. No. of miles per State per year with IRI between 60-94in/mi	831.20	613.71	0	3,636
	Avg. No. of miles per State per year with IRI between 95-170in/mi	684.31	602.08	0	3,100
	Avg. No. of miles per State per year with IRI greater than 170in/mi	71.53	90.20	0	415
	Avg. Preservation expenditure per State per year (in million US dollars)	54.45	50.96	0	285.18
RMA	Avg. No. of miles per State per year with IRI less than 60in/mi	290.29	492.26	0	4,364
	Avg. No. of miles per State per year with IRI between 60-94in/mi	1,027.34	879.83	0	4,626
	Avg. No. of miles per State per year with IRI between 95-170in/mi	1,167.37	1,032.80	0	5,551
	Avg. No. of miles per State per year with IRI greater than 170in/mi	167.08	233.27	0	1,660
	Avg. Preservation expenditure per State per year (in million US dollars)	52.98	50.91	0	387.89
RC	Avg. No. of miles per State per year with IRI less than 60in/mi	233.51	436.79	0	3,119
	Avg. No. of miles per State per year with IRI between 60-94in/mi	1,201.63	1,408.88	0	6,513
	Avg. No. of miles per State per year with IRI between 95-170in/mi	2,512.51	3,828.17	0	26,440
	Avg. No. of miles per State per year with IRI greater than 170in/mi	906.13	1,463.36	0	8,110
	Avg. Preservation expenditure per State per year (in million US dollars)	38.50	48.69	0	359.98
UI	Avg. No. of miles per State per year with IRI less than 60in/mi	44.33	74.25	0	410
	Avg. No. of miles per State per year with IRI between 60-94in/mi	105.66	97.95	0	521
	Avg. No. of miles per State per year with IRI between 95-170in/mi	109.52	126.71	0	717
	Avg. No. of miles per State per year with IRI greater than 170in/mi	19.00	37.09	0	341
	Avg. Preservation expenditure per State per year (in million US dollars)	47.56	77.60	0	700.84
UO	Avg. No. of miles per State per year with IRI less than 60in/mi	15.05	28.62	0	195
	Avg. No. of miles per State per year with IRI between 60-94in/mi	65.87	88.59	0	479
	Avg. No. of miles per State per year with IRI between 95-170in/mi	89.62	159.98	0	954
	Avg. No. of miles per State per year with IRI greater than 170in/mi	17.91	40.00	0	331
	Avg. Preservation expenditure per State per year (in million US dollars)	29.88	41.11	0	279.68
UPA	Avg. No. of miles per State per year with IRI less than 60in/mi	59.09	151.61	0	1,629
	Avg. No. of miles per State per year with IRI between 60-94in/mi	206.89	261.53	0	1,804
	Avg. No. of miles per State per year with IRI between 95-170in/mi	480.05	553.15	0	2,790
	Avg. No. of miles per State per year with IRI greater than 170in/mi	297.74	496.94	0	3,150
	Avg. Preservation expenditure per State per year (in million US dollars)	24.60	35.32	0	228.34
UMA	Avg. No. of miles per State per year with IRI less than 60in/mi	80.33	352.98	0	2,763
	Avg. No. of miles per State per year with IRI between 60-94in/mi	145.35	203.57	0	1,246
	Avg. No. of miles per State per year with IRI between 95-170in/mi	463.71	660.28	0	4,035
	Avg. No. of miles per State per year with IRI greater than 170in/mi	340.07	853.24	0	6,318
	Avg. Preservation expenditure per State per year (in million US dollars)	20.91	32.25	0	199.25
UC	Avg. No. of miles per State per year with IRI less than 60in/mi	57.20	301.54	0	2,690
	Avg. No. of miles per State per year with IRI between 60-94in/mi	52.37	118.05	0	1,521
	Avg. No. of miles per State per year with IRI between 95-170in/mi	274.04	519.97	0	3,529
	Avg. No. of miles per State per year with IRI greater than 170in/mi	371.08	1,028.45	0	7,420
	Avg. Preservation expenditure per State per year (in million US dollars)	18.82	23.08	0	149.45

* RI: Rural Interstate / RPA: Rural Principal Arterial / RMA: Rural Minor Arterial / RC: Rural Collector / UI: Urban Interstate / UO: Urban Other Freeways/Expressways / UPA: Urban Principal Arterial / UMA: Urban Minor Arterial / UC: Urban Collector

TABLE 2 Model Estimation Results for Rural Roads (Standard Errors in Parentheses)

	RI	RPA	RMA	RC
Proportion of miles with IRI less than 60in/mi in Period *t* :				
Constant	2.32 (0.035)	1.481 (0.014)	0.769 (0.014)	-1.046 (0.010)
Std.Dev. of parameter distribution		*1.032 (0.134)*	*0.932 (0.193)*	
No. of 100ths miles with IRI less than 60in/mi in Period *t*-1	0.390 (0.004)	0.169 (0.001)	0.103 (0.006)	0.114 (0.005)
Std.Dev. of parameter distribution			*0.089 (0.015)*	
Preservation expenditure per ln-mi in Period *t*-1 (in million US dollars)	0.008 (0.002)			0.004 (0.001)
Weather indicator variable (1 if freeze zone, 0 otherwise)	-0.097 (0.014)	-0.168 (0.009)		-0.27 (0.010)
Surface geology indicator variable (1 if residual soils, 0 otherwise)			-0.455 (0.013)	
Std.Dev. of parameter distribution			*0.239 (0.044)*	
Surface geology indicator variable (1 if coastal plain soils, 0 otherwise)			-0.23 (0.017)	0.224 (0.012)
Std.Dev. of parameter distribution			*0.124 (0.010)*	
Surface geology indicator variable (1 if alluvium, or lacustrine soils, 0 otherwise)			-0.484 (0.103)	
Surface geology indicator variable (1 if glacial soils, 0 otherwise)	0.192 (0.017)	0.121 (0.011)		
Surface geology indicator variable (1 if lacustrine, loess, clay, or organic soils, 0 otherwise)	0.246 (0.026)	0.049 (0.020)		
Std.Dev. of parameter distribution	*0.206 (0.027)*	*0.268 (0.019)*		
Proportion of miles with IRI between 60-94in/mi in Period *t* :				
Constant	3.27 (0.034)	2.6 (0.016)	1.547 (0.018)	0.427 (0.006)
Std.Dev. of parameter distribution	*2.015 (0.303)*			
No. of 100ths miles with IRI between 60-94in/mi in Period *t*-1	0.152 (0.002)	0.063 (0.001)	0.051 (0.003)	0.034 (0.002)
Std.Dev. of parameter distribution				*0.023 (0.004)*
Preservation expenditure per ln-mi in Period *t*-1 (in million US dollars)		0.006 (0.001)		
Weather indicator variable (1 if wet zone, 0 otherwise)	-0.075 (0.011)	-0.122 (0.007)	-0.108 (0.005)	-0.211 (0.006)
Std.Dev. of parameter distribution				*0.132 (0.019)*
Surface geology indicator variable (1 if residual soils, 0 otherwise)	-0.117 (0.016)	-0.028 (0.01)	-0.074 (0.006)	-0.093 (0.004)
Std.Dev. of parameter distribution			*0.049 (0.003)*	*0.059 (0.007)*
Surface geology indicator variable (1 if filled valleys and outwash, or coastal plain soils, 0 otherwise)	-0.163 (0.016)	-0.093 (0.008)		
Std.Dev. of parameter distribution		*0.139 (0.011)*		
Surface geology indicator variable (1 if alluvium, or lacustrine soils, 0 otherwise)				0.025 (0.006)
Std.Dev. of parameter distribution				*0.023 (0.005)*
Surface geology indicator variable (1 if glacial soils, 0 otherwise)			0.41 (0.013)	

* RI: Rural Interstate / RPA: Rural Principal Arterial / RMA: Rural Minor Arterial / RC: Rural Collector

TABLE 2 (Cont'd) Model Estimation Results for Rural Roads (Standard Errors in Parentheses)

	RI	RPA	RMA	RC
Proportion of miles with IRI between 95-170in/mi in period *t* :				
Constant	2.285 (0.035)	2.21 (0.016)	1.48 (0.018)	1.086 (0.006)
Std.Dev. of parameter distribution	*1.029 (0.098)*			*1.009 (0.095)*
No. of 100ths miles with IRI between 95-170in/mi in Period *t*-1	-0.326 (0.003)	-0.048 (0.001)	-0.046 (0.004)	0.011 (0.002)
Std.Dev. of parameter distribution	*0.204 (0.032)*	*0.027 (0.003)*	*0.031 (0.004)*	
Preservation expenditure per ln-mi in Period *t*-1 (in million US dollars)		-0.004 (0.001)	-0.005 (0.001)	-0.003 (0.001)
Std.Dev. of parameter distribution			*0.006 (0.002)*	
Weather indicator variable (1 if freeze zone, 0 otherwise)	0.125 (0.014)	0.083 (0.007)	0.085 (0.006)	
Std.Dev. of parameter distribution			*0.067 (0.007)*	
Weather indicator variable (1 if wet zone, 0 otherwise)				0.107 (0.006)
Std.Dev. of parameter distribution				*0.073 (0.005)*
Surface geology indicator variable (1 if residual soils, 0 otherwise)	0.028 (0.016)	0.033 (0.010)		
Std.Dev. of parameter distribution		*0.024 (0.005)*		
Surface geology indicator variable (1 if coastal plain soils, 0 otherwise)				0.107 (0.006)
Surface geology indicator variable (1 if glacial soils, 0 otherwise)			0.35 (0.013)	
Std.Dev. of parameter distribution			*0.281 (0.022)*	
Proportion of miles with IRI greater than 170in/mi in Period *t* :				
No. of 100ths miles with IRI greater than 170in/mi in Period *t*-1	2.582 (0.034)	0.598 (0.007)	0.193 (0.011)	-0.036 (0.002)
Preservation expenditure per ln-mi in Period *t*-1 (in million US dollars)	-0.007 (0.003)		-0.003 (0.001)	-0.002 (0.001)
Weather indicator variable (1 if freeze zone, 0 otherwise)	0.070 (0.014)			
Weather indicator variable (1 if wet zone, 0 otherwise)	0.076 (0.033)	0.102 (0.014)		
Surface geology indicator variable (1 if residual soils, 0 otherwise)			-0.264 (0.012)	-0.055 (0.006)
Surface geology indicator variable (1 if coastal plain soils, 0 otherwise)			-0.447 (0.018)	
Surface geology indicator variable (1 if alluvium, 0 otherwise)	0.236 (0.066)			
Surface geology indicator variable (1 if glacial soils, 0 otherwise)		-0.050 (0.018)		-0.146 (0.007)
Surface geology indicator variable (1 if lacustrine, loess, clay, or organic soils, 0 otherwise)				0.129 (0.017)

* RI: Rural Interstate / RPA: Rural Principal Arterial / RMA: Rural Minor Arterial / RC: Rural Collector

TABLE 3 Model Estimation Results for Urban Roads (Standard Errors in Parentheses)

	UI	UO	UPA	UMA	UC
Proportion of miles with IRI less than 60in/mi in Period *t* :					
Constant	1.151 (0.036)	0.317 (0.048)	-0.912 (0.020)	-1.537 (0.017)	-2.476 (0.020)
Std.Dev. of parameter distribution			*0.775 (0.051)*	*1.038 (0.083)*	
No. of 100ths miles with IRI less than 60in/mi in Period *t*-1	0.718 (0.008)	1.462 (0.039)	0.392 (0.004)	0.176 (0.002)	0.327 (0.002)
Std.Dev. of parameter distribution					*0.422 (0.023)*
Preservation expenditure per ln-mi in Period *t*-1 (in million US dollars)			0.002 (0.001)	0.006 (0.002)	
Weather indicator variable (1 if freeze zone, 0 otherwise)	-0.523 (0.022)	-0.512 (0.036)			-0.726 (0.079)
Weather indicator variable (1 if wet zone, 0 otherwise)			-0.219 (0.021)	-0.982 (0.079)	
Std.Dev. of parameter distribution			*0.161 (0.014)*		
Surface geology indicator variable (1 if alluvium, 0 otherwise)			-0.306 (0.018)		
Std.Dev. of parameter distribution			*0.152 (0.014)*		
Surface geology indicator variable (1 if residual soils, 0 otherwise)					-0.352 (0.027)
Std.Dev. of parameter distribution					*0.230 (0.028)*
Surface geology indicator variable (1 if alluvium, 0 otherwise)	-0.177 (0.050)	-0.189 (0.080)			
Surface geology indicator variable (1 if glacial soils, 0 otherwise)				0.639 (0.018)	
Surface geology indicator variable (1 if lacustrine soils, 0 otherwise)	0.595 (0.047)	0.239 (0.077)			
Std.Dev. of parameter distribution	*0.312 (0.067)*	*0.171 (0.076)*			
Proportion of miles with IRI between 60-94in/mi in Period *t* :					
Constant	1.832 (0.036)	1.746 (0.032)	0.195 (0.013)	-0.57 (0.015)	-1.472 (0.016)
Std.Dev. of parameter distribution	*1.049 (0.051)*				*1.019 (0.058)*
No. of 100ths miles with IRI between 60-94in/mi in Period *t*-1	0.37 (0.007)	0.37 (0.013)	0.154 (0.002)	0.183 (0.002)	0.139 (0.004)
Std.Dev. of parameter distribution			*0.212 (0.038)*	*0.159 (0.016)*	
Preservation expenditure per ln-mi in Period *t*-1 (in million US dollars)					0.003 (0.001)
Weather indicator variable (1 if freeze zone, 0 otherwise)	-0.201 (0.017)	-0.44 (0.021)	-0.192 (0.016)	-0.28 (0.010)	-0.241 (0.017)
Surface geology indicator variable (1 if residual soils, 0 otherwise)		0.082 (0.024)		0.146 (0.012)	
Surface geology indicator variable (1 if filled valleys and outwash, or coastal plain soils, 0 otherwise)				0.132 (0.015)	
Surface geology indicator variable (1 if coastal plain soils, 0 otherwise)	0.18 (0.022)				
Surface geology indicator variable (1 if glacial soils, 0 otherwise)	0.201 (0.018)		0.106 (0.011)		-0.106 (0.019)
Std.Dev. of parameter distribution					*0.115 (0.017)*

* UI: Urban Interstate / UO: Urban Other Freeways/Expressways / UPA: Urban Principal Arterial / UMA: Urban Minor Arterial / UC: Urban Collector

TABLE 3 (Cont'd) Model Estimation Results for Urban Roads (Standard Errors in Parentheses)

	UI	UO	UPA	UMA	UC
Proportion of miles with IRI between 95-170in/mi in Period *t* :					
Constant	1.681 (0.033)	1.498 (0.025)	0.886 (0.012)	0.429 (0.009)	-0.199 (0.010)
No. of 100ths miles with IRI between 95-170in/mi in Period *t*-1	0.358 (0.033)	0.284 (0.004)	0.074 (0.001)	0.069 (0.001)	0.068 (0.001)
Preservation expenditure per ln-mi in Period *t*-1 (in million US dollars)	-0.007 (0.001)			-0.002 (0.001)	0.002 (0.001)
Weather indicator variable (1 if freeze zone, 0 otherwise)			0.119 (0.015)		
Surface geology indicator variable (1 if residual soils, 0 otherwise)	-0.074 (0.017)	0.103 (0.027)	-0.092 (0.008)		
Std.Dev. of parameter distribution		*0.050 (0.013)*	*0.060 (0.005)*		
Surface geology indicator variable (1 if coastal plain soils, 0 otherwise)					-0.103 (0.018)
Surface geology indicator variable (1 if alluvium, or lacustrine soils, 0 otherwise)				-0.278 (0.014)	
Std.Dev. of parameter distribution				*0.488 (0.032)*	
Surface geology indicator variable (1 if alluvium, 0 otherwise)					-0.697 (0.019)
Std.Dev. of parameter distribution					*0.505 (0.035)*
Surface geology indicator variable (1 if lacustrine, loess, clay, or organic soils, 0 otherwise)		-0.279 (0.039)	-0.121 (0.017)		
Std.Dev. of parameter distribution		*0.182 (0.041)*	*0.227 (0.048)*		
Proportion of miles with IRI greater than 170in/mi in Period *t* :					
No. of 100ths miles with IRI greater than 170in/mi in Period *t*-1		1.058 (0.015)	0.105 (0.001)	0.059 (0.004)	0.042 (0.002)
Std.Dev. of parameter distribution			*0.084 (0.006)*	*0.055 (0.003)*	
Preservation expenditure per ln-mi in Period *t*-1 (in million US dollars)		-0.008 (0.001)			
Weather indicator variable (1 if freeze zone, 0 otherwise)	0.118 (0.031)		0.482 (0.016)	0.165 (0.009)	0.086 (0.010)
Std.Dev. of parameter distribution				*0.118 (0.006)*	
Weather indicator variable (1 if wet zone, 0 otherwise)		0.424 (0.096)			
Surface geology indicator variable (1 if residual soils, 0 otherwise)	-0.138 (0.029)			0.054 (0.008)	
Std.Dev. of parameter distribution				*0.111 (0.007)*	
Surface geology indicator variable (1 if filled valleys and outwash, or coastal plain soils, 0 otherwise)	0.377 (0.041)				
Std.Dev. of parameter distribution	*0.193 (0.059)*				
Surface geology indicator variable (1 if filled valleys and outwash, or glacial soils, 0 otherwise)					-0.281 (0.011)
Surface geology indicator variable (1 if coastal plain, or lacustrine soils, 0 otherwise)					-0.201 (0.016)
Std.Dev. of parameter distribution					*0.146 (0.010)*
Surface geology indicator variable (1 if coastal plain soils, 0 otherwise)			0.133 (0.016)		
Std.Dev. of parameter distribution			*0.137 (0.012)*		
Surface geology indicator variable (1 if lacustrine, loess, clay, or organic soils, 0 otherwise)		-0.245 (0.042)			
Std.Dev. of parameter distribution		*0.171 (0.037)*			

* UI: Urban Interstate / UO: Urban Other Freeways/Expressways / UPA: Urban Principal Arterial / UMA: Urban Minor Arterial / UC: Urban Collector

TABLE 4 Goodness-Of-Fit of the Developed Models

	RI		RPA	RMA	RC
Number of Observations	408		408	408	408
LL(β)	-123545.31		-409091.86	-497915.46	-1038572.44
LL(0)	-309638.56		-934148.96	-1312617.98	-2432601.81
R^2	0.601		0.562	0.621	0.573
	UI	UO	UPA	UMA	UC
Number of Observations	408	408	408	408	408
LL(β)	-61083.92	-42947.06	-210784.12	-179344.73	-108849.56
LL(0)	-139350.33	-94304.06	-523760.03	-519637.29	-378590.15
R^2	0.562	0.544	0.597	0.655	0.712

* RI: Rural Interstate / RPA: Rural Principal Arterial / RMA: Rural Minor Arterial / RC: Rural Collector / UI: Urban Interstate / UO: Urban Other Freeways/Expressways / UPA: Urban Principal Arterial / UMA: Urban Minor Arterial / UC: Urban Collector

TABLE 5 Percentage Change in the No. of Miles in IRI Categories due to Independent Variables for Rural and Urban Road Functional Classes

	RI	RPA	RMA	RC
Proportion of miles with IRI less than 60in/mi in Period *t* :				
No. of 100ths miles with IRI less than 60in/mi in Period *t*-1	0.377	0.362	0.222	0.241
Preservation expenditure per ln-mi in Period *t*-1 (in million US dollars)	0.016			0.019
Weather indicator variable (1 if freeze zone, 0 otherwise)	-0.053	-0.067		-0.179
Surface geology indicator variable (1 if residual soils, 0 otherwise)			-0.200	
Surface geology indicator variable (1 if coastal plain soils, 0 otherwise)			-0.031	0.033
Surface geology indicator variable (1 if alluvium, or lacustrine soils, 0 otherwise)			-0.040	
Surface geology indicator variable (1 if glacial soils, 0 otherwise)	0.034	0.024		
Surface geology indicator variable (1 if lacustrine, loess, clay, or organic soils, 0 otherwise)	0.010	0.005		
Proportion of miles with IRI between 60-94in/mi in Period *t* :				
No. of 100ths miles with IRI between 60-94in/mi in Period *t*-1	0.224	0.284	0.301	0.297
Preservation expenditure per ln-mi in Period *t*-1 (in million US dollars)		0.040		
Weather indicator variable (1 if wet zone, 0 otherwise)	-0.018	-0.033	-0.033	-0.077
Surface geology indicator variable (1 if residual soils, 0 otherwise)	-0.031	-0.007	-0.022	-0.008
Surface geology indicator variable (1 if filled valleys and outwash, or coastal plain soils, 0 otherwise)	-0.015	-0.009		
Surface geology indicator variable (1 if alluvium, or lacustrine soils, 0 otherwise)				0.006
Surface geology indicator variable (1 if glacial soils, 0 otherwise)			0.058	
Proportion of miles with IRI between 95-170in/mi in Period *t* :				
No. of 100ths miles with IRI between 95-170in/mi in Period *t*-1	-0.378	0.356	-0.291	0.134
Preservation expenditure per ln-mi in Period *t*-1 (in million US dollars)		-0.030	-0.001	-0.043
Weather indicator variable (1 if freeze zone, 0 otherwise)	0.064	0.037	0.033	
Weather indicator variable (1 if wet zone, 0 otherwise)				0.021
Surface geology indicator variable (1 if residual soils, 0 otherwise)	0.010	0.010		
Surface geology indicator variable (1 if coastal plain soils, 0 otherwise)				0.008
Surface geology indicator variable (1 if glacial soils, 0 otherwise)			0.048	
Proportion of miles with IRI greater than 170in/mi in Period *t* :				
No. of 100ths miles with IRI greater than 170in/mi in Period *t*-1	0.317	0.417	0.298	-0.260
Preservation expenditure per ln-mi in Period *t*-1 (in million US dollars)	-0.178		-0.011	-0.027
Weather indicator variable (1 if freeze zone, 0 otherwise)			0.073	
Weather indicator variable (1 if wet zone, 0 otherwise)	0.035	0.047		
Surface geology indicator variable (1 if residual soils, 0 otherwise)			-0.121	-0.023
Surface geology indicator variable (1 if coastal plain soils, 0 otherwise)			-0.065	
Surface geology indicator variable (1 if alluvium, 0 otherwise)	0.012			
Surface geology indicator variable (1 if glacial soils, 0 otherwise)		-0.011		-0.029
Surface geology indicator variable (1 if lacustrine, loess, clay, or organic soils, 0 otherwise)				0.044

Note: Table values are for a response to a 1% change for the continuous variables and changes from 0 to 1 for the indicator variables

* RI: Rural Interstate / RPA: Rural Principal Arterial / RMA: Rural Minor Arterial / RC: Rural Collector

TABLE 5 (Cont'd) Percentage Change in the Number of Miles in IRI Categories due to Independent Variables for Rural and Urban Road Functional Classes

	UI	UO	UPA	UMA	UC
Proportion of miles with IRI less than 60in/mi in Period *t* :					
No. of 100ths miles with IRI less than 60in/mi in Period *t*-1	0.205	0.194	0.169	0.067	0.052
Preservation expenditure per ln-mi in Period *t*-1 (in million US dollars)			0.002	0.049	
Weather indicator variable (1 if freeze zone, 0 otherwise)	-0.322	-0.319			-0.160
Weather indicator variable (1 if wet zone, 0 otherwise)			-0.103	-0.019	
Surface geology indicator variable (1 if alluvium, 0 otherwise)	-0.008				
Surface geology indicator variable (1 if residual soils, 0 otherwise)					-0.168
Surface geology indicator variable (1 if alluvium, 0 otherwise)		-0.008	-0.158		
Surface geology indicator variable (1 if glacial soils, 0 otherwise)				0.135	
Surface geology indicator variable (1 if lacustrine soils, 0 otherwise)	0.018	0.005			
Proportion of miles with IRI between 60-94in/mi in Period *t* :					
No. of 100ths miles with IRI between 60-94in/mi in Period *t*-1	0.225	0.162	0.225	0.214	0.067
Preservation expenditure per ln-mi in Period *t*-1 (in million US dollars)					0.005
Weather indicator variable (1 if freeze zone, 0 otherwise)	-0.084	-0.190	-0.075	-0.169	-0.152
Surface geology indicator variable (1 if residual soils, 0 otherwise)		0.025		0.061	
Surface geology indicator variable (1 if filled valleys and outwash, or coastal plain soils, 0 otherwise)				0.018	
Surface geology indicator variable (1 if coastal plain soils, 0 otherwise)	0.017				
Surface geology indicator variable (1 if glacial soils, 0 otherwise)	0.028		0.020		-0.023
Proportion of miles with IRI between 95-170in/mi in Period *t* :					
No. of 100ths miles with IRI between 95-170in/mi in Period *t*-1	0.223	0.143	0.182	0.163	0.107
Preservation expenditure per ln-mi in Period *t*-1 (in million US dollars)	-0.012			-0.006	0.002
Weather indicator variable (1 if freeze zone, 0 otherwise)			0.044		
Surface geology indicator variable (1 if residual soils, 0 otherwise)	-0.023	0.029	-0.025		
Surface geology indicator variable (1 if coastal plain soils, 0 otherwise)					-0.010
Surface geology indicator variable (1 if alluvium, or lacustrine soils, 0 otherwise)				-0.026	
Surface geology indicator variable (1 if alluvium, 0 otherwise)					-0.028
Surface geology indicator variable (1 if lacustrine, loess, clay, or organic soils, 0 otherwise)		-0.009	-0.004		
Proportion of miles with IRI greater than 170in/mi in Period *t* :					
No. of 100ths miles with IRI greater than 170in/mi in Period *t*-1		0.192	0.202	0.114	0.064
Preservation expenditure per ln-mi in Period *t*-1 (in million US dollars)		-0.039			
Weather indicator variable (1 if freeze zone, 0 otherwise)	0.052		0.240	0.077	0.031
Weather indicator variable (1 if wet zone, 0 otherwise)		0.008			
Surface geology indicator variable (1 if residual soils, 0 otherwise)	-0.064			0.018	
Surface geology indicator variable (1 if filled valleys and outwash, or coastal plain soils, 0 otherwise)	0.041				
Surface geology indicator variable (1 if filled valleys and outwash, or glacial soils, 0 otherwise)					-0.040
Surface geology indicator variable (1 if coastal plain, or lacustrine soils, 0 otherwise)					-0.021
Surface geology indicator variable (1 if coastal plain soils, 0 otherwise)			0.015		
Surface geology indicator variable (1 if lacustrine, loess, clay, or organic soils, 0 otherwise)		-0.013			

Note: Table values are for a response to a 1% change for the continuous variables and changes from 0 to 1 for the indicator variables
* UI: Urban Interstate / UO: Urban Other Freeways/Expressways / UPA: Urban Principal Arterial / UMA: Urban Minor Arterial / UC: Urban Collector

TABLE 6 Summarized Trends on Pavement Condition*

	RI	RPA	RMA	RC	UI	UO	UPA	UMA	UC
Excellent pavement condition in Period *t*-1 (in excellent pavement condition roads)	+	+	(+)	+	+	+	+	+	(+)
Good pavement condition in Period *t*-1 (in good pavement condition roads)	+	+	+	(+)	+	+	(+)	(+)	+
Fair pavement condition in Period *t*-1 (in fair pavement condition roads)	(–)	(–)	(–)	+	+	+	+	+	+
Poor pavement condition in Period *t*-1 (in poor pavement condition roads)	+	+	+	–	N/A	+	(+)	(+)	+
Preservation expenditure in Period *t*-1	+	+	+	+	+	+	+	+	+
Freeze zone	–	–	(–)	–	–	–	–	(–)	–
Wet zone	–	–	–	(–)	N/A	–	(–)	–	N/A
Residual soils	–	(–)	(–)	(–)	+	(+)	(+)	(+)	(–)
Coastal plain soils	–	(–)	(–)	(+)	(+)	N/A	(–)	+	(+)
Glacial soils	+	+	(+)	+	+	N/A	+	+	(+)
Alluvium	–	N/A	–	(+)	–	–	(–)	(+)	(+)
Lacustrine soils	(+)	(+)	–	(+)	(+)	(+)	(+)	(+)	(+)
Loess, clay, or organic soils	(+)	(+)	N/A	–	N/A	(+)	(+)	N/A	N/A
Filled valleys and outwash	–	(–)	N/A	N/A	(–)	N/A	N/A	+	+

* RI: Rural Interstate / RPA: Rural Principal Arterial / RMA: Rural Minor Arterial / RC: Rural Collector / UI: Urban Interstate / UO: Urban Other Freeways/Expressways / UPA: Urban Principal Arterial / UMA: Urban Minor Arterial / UC: Urban Collector / N/A: Not Available

Note: The ‘+’ indicates a positive effect on the overall pavement condition, whereas ‘–’ indicates a negative effect. The signs in parentheses indicate that the suggested effect is not uniform across the States.